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Effects of geomagnetic activity and atmospheric power variations on quantitative measures of brain activity: Replication of the Azerbaijani studies

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Abstract

This study replicates and extends the observations by Babayev and Allahveriyeva that changes in right hemispheric electroencephalographic activity are correlated with increases in geomagnetic activity. During the geomagnetically quiet interface between solar cycle 23 and 24 quantitative electroencephalographic (QEEG) measurements were completed for normal young adults in three separate experiments involving about 120 samples over 1.5 years. The most consistent, moderate strength correlations occurred for the changes in power within the gamma and theta ranges over the right frontal lobe. Real-time measures of atmospheric power obtained from polar orbiting satellites showed similar effects. The preferential involvement of the right frontal lobe and the regions subject to its inhibition with environmental energetic changes are consistent with the behavioural correlations historically associated with these conditions. They include increased incidence of emotional lability, erroneous reconstruction of experiences, social confrontations, and unusual perceptions.
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1. Introduction

Geomagnetic activity has been correlated moderately ($r = 0.4$–$r = 0.6$) with multiple inferences of cerebral electrical lability, such as epileptic seizures (Rajaram and Mitra, 1981), visual (bereavement) hallucinations (Persinger, 1988; Randall and Randall, 1991) and electroencephalographic (EEG) patterns (Booth et al, 2005). Ictal activity and correlative visual hallucinations have been experimentally produced by transcerebral application of weak physiologically-patterned magnetic fields (Persinger et al, 2000). Experimental simulation of the temporal pattern and intensity (20 nT–50 nT) of geomagnetic activity produced limbic motor seizures in epileptic rats that were comparable in incidence to those associated with increased (20–50 nT) geomagnetic activity (Michon et al., 1996).

Recently Babayev and Allahverdiyeva, employing quantitative electroencephalographic (QEEG) technology, demonstrated conspicuous and specific changes in alpha (8–13 Hz) and theta (4–7 Hz) activity within the right hemispheres of normal subjects during major geomagnetic storms. We report here similar quantitative electroencephalographic correlations, primarily involving the right hemisphere, during the much less intense periods of recent geomagnetic activity during the hiatus between Solar Cycle 23 and 24 in samples of healthy young adults. The magnitude of global (and local) geomagnetic variations was within the range (15–20 nT) correlated with enhanced vestibular experiences during partial sensory deprivation in healthy adults (Persinger and Richards, 1995). The associated K_p (planetary-K) index (Campbell, 1997) is approximately between 0 and 3 for these values and the global geomagnetic activity is considered quiet to unsettled.

The potential sensitivity or greater receptivity of the right hemisphere of the human brain to ambient geomagnetic

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activity was inferred by Belisheva et al. (1995) who demonstrated that increased geomagnetic activity was associated with altered visual thresholds in the left peripheral visual fields of astronauts. Del Seppia et al. (2006) found that simulation of the geomagnetic field experienced by the International Space Station in its revolution around the earth enhanced autonomic responses to emotional stimuli. Both observations are consistent with increased right hemispheric activation.

Experimentally applied and physiologically-patterned magnetic fields maintain right hemispheric alpha activity (Persinger, 1999a) and facilitate right hemispheric functions (Healey et al., 1996, 1997; Sandyk, 1995). Temporally complex and changing weak magnetic fields, more typical of geomagnetic patterns, entrain EEG activity after about 15 min (Persinger et al., 1997). Both experimental and correlational data (Booth et al., 2003, 2005) indicate that increases in magnetic field intensities in the order of a pT/s for about 10 min to 15 min are associated with increased experiences of a "sensed presence of another" (Persinger, 1993) whose origin has been attributed to the normal intrusion of right hemispheric "information" into left hemispheric awareness during specific altered states (Persinger, 2003; Persinger and Healey, 2002).

If changes in geomagnetic activity preferentially affect the right hemisphere of the human being, then subtle changes in global geomagnetic activity could affect behaviour of the human population on the earth's surface as well as those living in the near-earth space environment. Although the person would not be "aware" of these changes, they could affect decision-making (Healey et al, 1997; Ross et al, 2008). Right hemispheric processes are strongly correlated with hunches, intuition, and mood particularly when novel information for which there are no a priori verbal labels has been presented (Budzynski, 1986).

That biological systems evolved within and are constantly immersed within the geomagnetic field indicates sensitivity to minute changes should exist (Presman, 1970; Cole and Graf, 1974; Johnson et al., 2008). There is copious evidence that organisms and cells are sensitive to electric field gradients as low as 10^{-8} V/cm (Adey, 1981; Gailey, 1999). According to Adey and Bawin (1977), given an approximately 100 Hz bandwidth for typical physiological systems this is the threshold value to exceed thermal noise. This value is also within an order of magnitude of the 4×10^{-6} V/cm of the earth's electric field associated with the potential difference produced by reconnections of the earth's magnetic flux lines when solar-wind energy enters the magnetosphere (Phan et al., 2000).

We have been pursuing the model that the effects of changes from ambient geomagnetic fluctuations upon human brain activity is similar to the dynamic flux-line interaction between the magnetic field of the solar wind, whose intensity is about 7–10 nT, and the geomagnetic field. Consequently the primary effect would occur more within the domain of the organization of the temporal structure of the fluctuations in energy or power within the brain than the amount of current induction or energy produced by that interaction.

A summary of the parameters for the three experiments outlined below is presented in Table 1.

2. Experiment I: correlations between EEG spectral power data and daily/hourly indices of geomagnetic activity derived from ground-based magnetic observatories

2.1. Materials and methods

A subject data base (15 subjects, 90 samples) was developed from multiple studies where subjects' eyes-closed records were recorded over a 1.5 year period in Sudbury, Ontario, Canada (46.5 N, 81.0 W). The data had been obtained for subsequent comparisons of responses to various operations in other studies. All subjects had been seated in a comfortable arm chair. Ag–AgCl electrodes adhered to the scalp by EC-2 cream were placed in standard O1, O2 (occipital), T3, T4 (temporal), P3, P4 (parietal) and F7, F8 (frontal) positions. The measurements were unipolar referenced to the left earlobe. Two minutes after the eyes had been closed, without the subjects' knowledge, 30 s of artifact-free EEG data were collected by computer.

Our quantitative EEG (QEEG) system employed a Grass Instruments Model 8-16C, 16 Channel EEG (pass filtered to between 1 and 70 Hz, notch filtered at 60 Hz) interfaced to an IBM computer via a 12 bit National Instruments Model AT-MIO-64E-3 ADC/DAC (Analogue to Digital Converter) card. The data were recorded with a resolution of 12 bits and a sample rate of 1 kHz. Data were analyzed into desired frequency components by utilizing a Fast Fourier Transform (FFT). Two separate bands were isolated with six ranges within each. The first (wide) band involved the traditional ranges: delta (1–4 Hz), theta (4–7 Hz), low-alpha (8–10.5 Hz), high-alpha (10.5–13 Hz), beta (13–35 Hz) and gamma (35–45 Hz). The second (narrow) band was specific for the theta range of 1 Hz increments (3–3.9 Hz to 8–8.9 Hz). The basis for analyzing 1-Hz bands in the theta (and neighbouring) frequency bands is based on both theoretical considerations (Persinger, 1999b) and empirical findings from our lab (Booth and Persinger, 2009). Both suggest that this range is related to specific subjective states.

Ground source planetary K-indices (K_p) measurements were acquired through www.solen.info/solar. The K index is a quasi-log ranking scale for the intensity (0–9) of the most active component of geomagnetic activity within continuous 3-h intervals and referenced to universal time. The equivalent real intensity values for the geomagnetic activity associated with each of the numbers between 0 and 9 range between 0 and >500 nT and are based on the average of 13 selected subauroral stations (Campbell, 1997).

For comparison with the QEEG data, the K_p value for each of the 3, 3 h increments (9 h) before and the intervals of the assessments (between 10 h and 14 h Eastern

Table 1
Breakdown of experimental parameters for the three reported studies.

Study #	# of subjects	# of EEG samples	EEG variables	Geophysical variables
1	15	90	Raw broadband (classic) spectral power,Raw 1-Hz increment spectral power between 3 and 8.9 Hz.	3-h K_p
2	9	45	Relative broadband (classic) spectral power,Relative 1-Hz increment spectral power between 3 and 8.9 Hz.	3-h A_p, Atmospheric power
3	1	43	Raw broadband (classic) spectral power,Wackermann's global linear descriptors.	Atmospheric power

Standard Time) were extracted from the data base for the interval between 1 July 2006 and 31 January 2008. The mean, SD, minimum and maximum values for the K_p indicators for the four intervals were: during ($M = 2.18$, $SD = 1.18$, 0–4), −3 h ($M = 1.37$, $SD = 1.15$, 0–3), −6 h ($M = 1.34$, $SD = 1.31$, 0–3), and −9 h ($M = 1.73$, $SD = 1.76$, 0–5). These values were associated with actual intensities between 0 and 70 nT with an average of about 20–25 nT.

The preliminary analyses involved parametric (Pearson product moment) and non-parametric (Spearman rho) analyses. Correlations were completed for the power values for each of the eight positions (O1, O2, T3, T4, P3, P4, F7, F8) for each of the frequency bands and the K_p values for each of the 4, 3 h intervals. To discern the EEG variables primarily involved, analyses of covariance and multiple regression (step wise, with maxsteps = 6 to minimize spurious entries) were completed. All analyses involved SPSS software on a Vax 4000 computer.

2.2. Results: broadband analyses

A summation of the results in Experiment 1 is listed in Table 2. As expected, due to coherence reflected as multiple, strong intercorrelations ($r > .70$) of power between the cerebral regions and frequency bands, there were large arrays of statistically significant correlations ($r > .20$, $p < .05$) between K_p values (geomagnetic activity) during the 3-h period of and the 3-h period before the QEEG measurements. Gamma activity within the left and right frontal lobes and right temporal and parietal lobes were most significantly correlated with K_p values for all four 3 h intervals. The most significant ($p < .001$) correlation ($r = -0.71$) occurred between geomagnetic activity and power within the gamma range within the right frontal region. When the correlation with the right frontal area was first removed by analyses of covariance the significant geomagnetic-power correlations for the other areas were eliminated.

Table 2
Correlations between right frontal and left parietal power measures with daily 3 h planetary K index measures.

Hemisphere	Lobe	Band	R
Right	Frontal	Gamma	−0.71
Left	Parietal	Beta	−0.66
Canonical R			0.73
Right	Frontal	8–8.9 Hz	−0.58
Left	Parietal	7–7.9 Hz	0.57
Canonical R			0.66

The only other wide band that was associated with geomagnetic activity was the beta range. After appropriate covariance, the strongest correlation occurred between the K_p values and the power over the left parietal lobe ($r = -0.66$). Power within this range for all other areas was no longer significant statistically. To discern the strength of effect a functional canonical correlation was completed between the beta power within the left parietal region and the gamma power within the right frontal region as dependent variables and the K_p value during the interval of the recording as the covariate. The equivalent multiple r was .73, which accommodated about 53% of the variance.

2.2.1. Theta-band

Spearman rho correlations again showed multiple significant correlations between power values within each of the 1 Hz intervals and K_p values during the 3-h interval of QEEG measurement. Partial correlational analyses revealed the strongest correlation ($r = -0.58$, $p < .001$) was between K_p values and power within the 8–8.9 Hz over the right frontal lobe. The only other consistent result was the correlation ($r = -0.57$, $p < .001$) involving the power within the 7–7.9 Hz band over the left parietal region. Again a functional canonical correlation with these two bands and regions with geomagnetic activity as the covariate resulted in correlation of .66.

3. Experiment 2: correlations between EEG spectral power and instantaneous contemporary estimates of atmospheric power derived from polar-orbiting satellites

3.1. Introduction

The Schumann-absorption model proposed by Cherry (2002) and others presumes that maximal energy transfer between weak magnetic variations within the geomagnetic–ionospheric system (Schlegel and Fuellekrug, 1999) occur when the exogenous frequencies correspond with those measured from the brain by electroencephalography. The peak absorption would involve the theta (4–8 Hz) and alpha (8–13 Hz) bands, which include the base and first harmonic of the Schumann resonance (Konig et al, 1981).

We reasoned that energy transfer could be inferred by more or less "instantaneous" increases and decreases in spectral power within the EEG theta band.

3.2. Materials and methods

All EEG data were collected between 9 and 20 March 2008 between 15 and 1830 h UTC (11 AM to 2:30 PM local time) in Sudbury, Ontario. Nine healthy young adults (4 male; 5 females) volunteered as subjects. One male and female were left-handed; the others were right handed. The subjects had been recruited for a spontaneous "thought monitoring" study whereby at random times over a 1 h period during continuous EEG monitoring the subjects were asked to specify what they had been thinking during the previous 5 s. Reported thought content was scored on a series of ordinal scales designed to reflect subjective level of vigilance and modality/perceived sources of imagery/sensations.

EEG recordings (unipolar, referenced to the left earlobe) were completed from the same frontal, temporal, parietal, and occipital positions as in Experiment 1. Each subject wore sound-dampening earmuffs and was blindfolded. During the recording period 5, 30-s epochs were obtained for each subject. Interepic period was 5–9 min. The raw data were transformed using the same device and procedures as Experiment I. The same two bands of EEG activity: wide (classic) band and 1-Hz increments within the theta region, were analyzed except relative power scores were utilized.

Relative power scores were obtained by subtracting the baseline measurements for each of the eight positions from the values for each of the five trials and dividing this difference by the baseline value. For example, the baseline power for F8 was subtracted from the average power for F8 for trial 1; this value was divided by the baseline. The relative scores were employed to minimize individual differences between subjects and within subjects. The latter reduced the strength and numbers of intracerebral correlations that are frequently associated with employing absolute power measures.

There were two sets of correlations: geomagnetic activity and atmospheric power. During the days of testing the 3-h A_p values ranged from 6–30 nT. A_p is a ratio scale magnetic activity index based on the K index and reported in units of nT (Campbell, 1997). Estimates of atmospheric power in Gigawatts (GW) were obtained from an online Space Environment Center database (http://www.swpc.noaa.gov/ftpdir/lists/hpi). The power values reflect measurements of the J/s absorbed in the polar regions of the atmosphere by NOAA POES satellites during transits over the poles. The satellites continually monitor the power flux carried by aurora-producing electrons and protons in the atmosphere. Although atmospheric power is highly correlated with the Ap and Kp indices of geomagnetic activity, it differs from the latter measures in terms of the time increment required to acquire the measurement. Whereas the K_p and A_p index reflect the largest deviation of the geomagnetic field from normal (in the horizontal plane) during a 3-h period, statistical atmospheric power estimates are generated using single polar passes (lasting approximately 25 min). The satellite observation timestamps (defined as UTC time at the midpoint of the polar pass) were used to match each EEG epoch with the most contemporary atmospheric power observation for either the North or South Pole. During the test days the mean and standard deviation (in parenthesis) for atmospheric power were 18.7 (11.1) GW.

The QEEG, geomagnetic, and atmospheric power values were assessed by both parametric (Pearson product moment r) and non-parametric (Spearman rho) procedures. Prediction of atmospheric power by EEG spectral power scores was modelled using multiple regression analyses. All data were analyzed using SPSS on a VAX 4000 computer.

3.3. Results

The presence of vestibular sensations and thoughts ascribed by subjects' to experiences from their past (as opposed to current or future experiences) were both negatively correlated with contemporary atmospheric power (rho = 0.30 and 0.23, $p < 0.02$ and 0.05 respectively).

For the geomagnetic correlations (A_p index), the strongest and most significant correlations for the wide-band were for gamma in the right temporal lobe and theta in the right parietal lobe. For the successive 1-Hz bands within the theta range, geomagnetic activity was correlated negatively with the 7–7.9 Hz band in the right frontal lobe while both the 3–3.9 Hz and 5–5.9 Hz bands were positively correlated within the right parietal lobe.

The most significant and consistent correlations between atmospheric power at the time of the EEG measurement and the regions and frequencies of brain activity are shown in Table 3. As atmospheric power increased during the recordings power within the theta band decreased within

Table 3
Pearson r and Spearman rho correlations ($p < .001$) between spectral power within the clinical bands and successive 1-Hz theta bands of EEG activity over various regions of the brain and the concurrent estimates of atmospheric power.

Hemisphere	Lobe	Band	R	Rho
Classic EEG bands				
Right	Frontal	Theta	−0.81	−0.74
Right	Temporal	Beta	0.38	0.32
Right	Temporal	Gamma	0.36	0.43
Left	Temporal	Gamma	0.36	0.34
1 Hz increments in theta range (3–9 Hz)				
Right	Frontal	5–5.9	−0.42	−0.49
Right	Frontal	6–6.9	−0.36	−0.41
Right	Frontal	7–7.9	−0.40	−0.37
Left	Temporal	4–4.9	0.42	0.32
Left	Temporal	8–8.9	0.41	0.27
Left	Parietal	4–4.9	0.39	0.37

the right frontal region while there was general activation in the beta range over the right temporal lobe and in the gamma range for the temporal lobes of both hemispheres. The scattergram showing the relationship with atmospheric power for the theta band and the specific 5.0–5.9 Hz band over the right frontal lobe is shown in Fig. 1.

The results of the multiple regression analyses are shown in Table 4. The first two (and strongest) variables to enter the equation were the decreased power over the right frontal lobe within the theta and increased power within the beta band over the right temporal lobe. Approximately 54% of the variance between the linear combination of power changes within these brain regions and frequencies was shared with the real-time (30 s EEG increments) variations in atmospheric power.

The significant correlations for the 1-Hz increments within the theta range are shown in Table 3. Power within the right frontal lobes for three adjacent increments (5 Hz–8 Hz) decreased with increased atmospheric power. On the other hand the EEG power over the temporal and parietal lobes within the delta–theta interface (4–4.9 Hz) increased with increased atmospheric power at the time of the measurements. The results of the multiple regression analysis for the 1-Hz increments are shown in Table 5. About 50% of the variance was shared between atmospheric power and the partial linear combination from the first two variables that entered the equation: decreased power

Table 4
Summary of multiple regression analysis showing the hemisphere, lobe, classical frequency band and their respective partial slopes (B), SEB (standard error of B) and cumulative multiple R.

Hemisphere	Lobe	Band	B	SEB	MR
Right	Frontal	Theta	−50.2	8.1	0.44
Right	Temporal	Beta	25.7	5.6	0.67
Left	Parietal	Delta	12.4	5.7	0.71
Right	Occipital	High alpha	−07.5	3.6	0.75
Constant	15.1 (1.4)				

Table 5
Summary of multiple regression analysis for 1-Hz increments within the theta range showing hemisphere, lobe, band, partial regression coefficients (B), SEB, and cumulative multiple R.

Hemisphere	Lobe	Band	B	SEB	MR
Right	Frontal	5–5.9	−17.2	3.8	0.42
Left	Temporal	4–4.9	9.3	7.5	0.63
Right	Frontal	6–6.9	−13.9	7.5	0.71
Left	Parietal	4–4.9	24.7	6.8	0.78
Right	Parietal	7–7.9	−13.9	3.2	0.81
Right	Parietal	3–3.9	13.6	4.1	0.85
Constant	19.3 (1.0)				

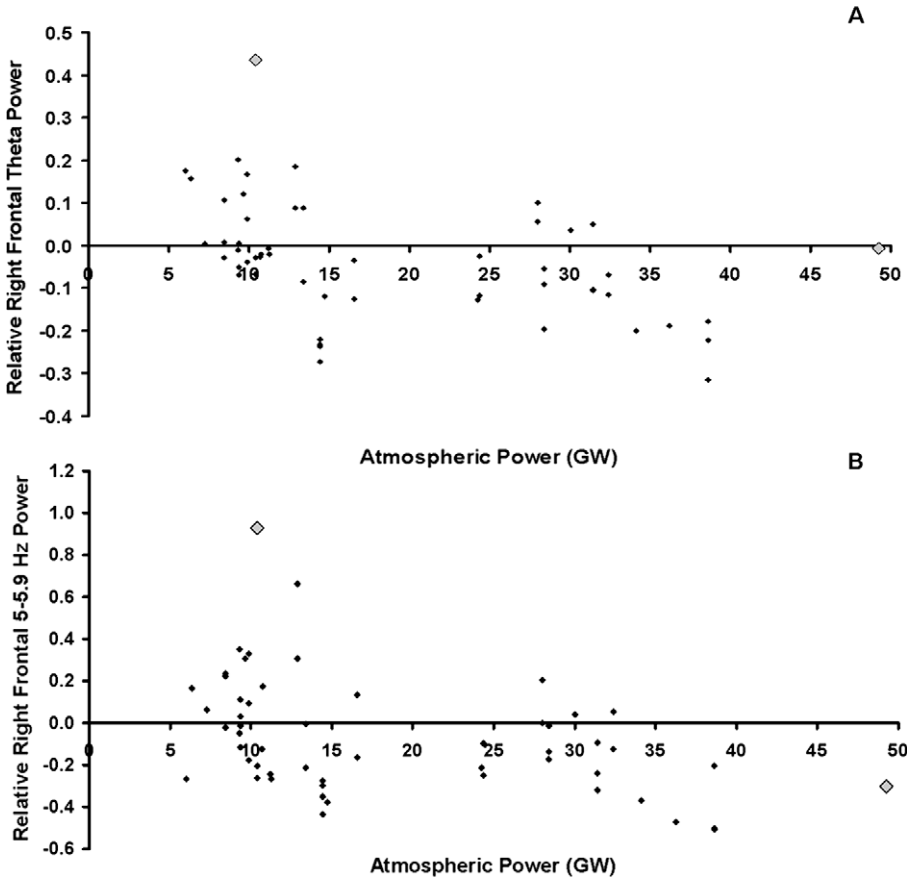

Fig. 1. Scatterplots (n = 54) of relative power within the theta range (A) and the 5.0–5.9 Hz range (B) over the right frontal lobe as a function of atmospheric power in Gigawatts. Exclusion of outliers (grey triangles) did not change the strength of the correlation coefficients.

within the right frontal lobe (5.0–6.9 Hz) and increased power (4.0–4.9 Hz) within the left temporal lobe.

4. Experiment 3: repeated measures of functional global EEG states for a single subject and atmospheric power

4.1. Introduction

Modern quantitative electroencephalographic methods reveal the intrinsic dynamics of brain activity. These configurations will be important to isolate the intrinsic information generated within the cerebrum as well as the potential exchange of energy and information with the external geomagnetic environment. In this experiment we measured a single subject over several weeks in order to compare atmospheric power with the complexity of cerebral activity.

Overall complexity, measured by Wackermann's (1999) omega, is similar to a measure of entropy. It is effectively a numerical value for the number of sine-waves required to simulate the temporal pattern of EEG activity. Classic, symmetrical alpha rhythmic spindles are minimally complex while irregularly-spaced burst-firing patterns, such as those associated with long-term potentiation (LTP) show maximum complexity. In addition to omega-complexity, two other global measures of brain activity: amplitude (in uV, Sigma) and frequency in Hz (Phi) have been developed (Wackermann, 1999).

4.2. Materials and methods

Over five weeks a total of 43, 30 s QEEG measurements were obtained from a single female (age 22 years) subject while she sat blindfolded in a comfortable chair. Unipolar measurements of the same eight cerebral regions described in the first two experiments were obtained through the same software. MapWin software was employed to generate Wackermann's 3 global linear descriptors: Sigma (amplitude, uV), Phi (frequency, Hz) and Omega (complexity, dimensionless) for all eight cerebral sites. The mean and standard deviations for the atmospheric power during these measurements were 10.5 and 8.5 GW. During the 43 EEG epochs recorded during July and August of 2008 atmospheric power and 3-h A_p values were strongly ($r = 0.93$, $rho = 0.70$, $p < .01$) correlated and both measures were negatively correlated with 10.7 cm radio flux ($r = -0.39$ and -0.32, respectively; $rho = -0.42$ and -0.54, respectively).

4.3. Results

Although there was no significant correlation between global complexity and atmospheric power, there was a moderate strength positive association ($r = .45$; $rho = .47$) between atmospheric power (in GW) and the omega complexity over the right frontal region. No other region displayed this effect. The scattergram is shown in Fig. 2.

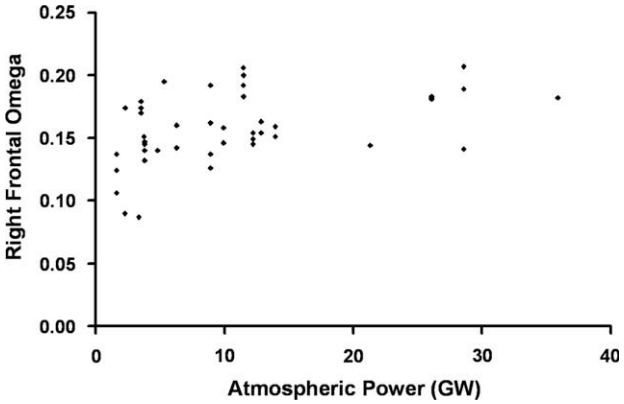

Fig. 2. Scatterplot of electroencephalographic complexity (Omega) over the right frontal region for 43 samples over five weeks for one subject as a function of atmospheric power during the sample periods.

On the other hand global frequency of the brain was strongly correlated ($r = 0.74$) with atmospheric power. As shown in Fig. 3, about 50% of the variance in the increase of the Phi (Hz) measure was accommodated by the increase in atmospheric power. Slope analyses indicated an averaged change of only about 5 Hz between 4 and 15 GW. Above 25 GW more marked global frequency increases occurred. Employing raw broadband spectral power scores, the only statistically significant ($p < .05$) bivariate associations were negative correlations between atmospheric power and power in the gamma range for the occipital ($r = -0.30$) and temporal ($r = -0.36$) regions of the right hemisphere only.

5. Discussion

The results of our measurements support the conclusions of Babayev and Allahverdiyeva (2007) that the electroencephalographic activity of normal people is correlated with ambient geomagnetic activity. We also found that the most consistent correlations occurred between geomagnetic activity as well as a strongly correlated measure, atmospheric power, and EEG power over the right frontal lobe.

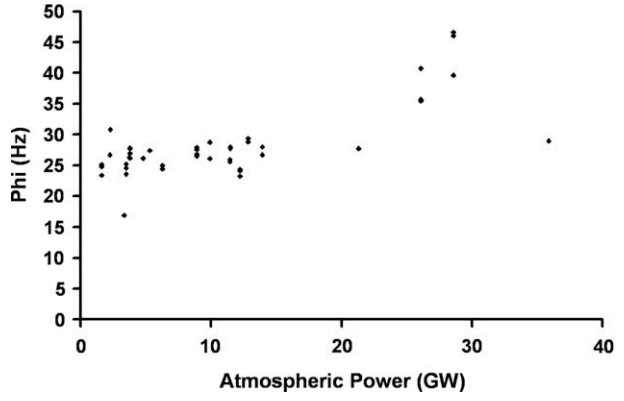

Fig. 3. Scatterplot of Phi (global EEG frequency) for one subject for 41 samples over five weeks as a function of atmospheric power during the sample periods.

The primary difference between our results and those reported by Babayev and Allahverdiyeva (2007) is that we did not observe qualitative differences in the electroencephalographic activity. Instead we measured reliable quantitative electroencephalographic changes that occurred with much less intense geomagnetic variations. Their qualitative EEG changes were noted primarily during days of intense magnetic storms when typical 3-h K_p values exceed 6, A_p values are around 100, and the intensity of the most disturbed component of the geomagnetic field is over 120 nT.

We found that about 20–40% of the variance in EEG power (with both multiple- and single-subject studies) in certain frequency bands over the right frontal region, in particular, was accommodated by daily variations in geomagnetic activity in the range of K_p values 1–4. This is equivalent to A_p values around 30 and intensity variations of about 25–30 nT. That this global averaged variation is sufficient to affect cognition has been reported previously. Persinger and Richards (1995) reported that a cluster of experiences loaded on a factor dominated by vestibular sensations significantly increased when global geomagnetic activity exceeded 15–20 nT.

The two frequency bands most consistently and strongly correlated with increased geomagnetic activity within the range that occurred during our study were gamma (35–45 Hz) and theta (4–7 Hz). The most parsimonious explanation for an intrinsic connection between these two non-adjacent bands involves a role of the hippocampal formation. These two bands involve the peak energy of the septal–hippocampal inputs. In addition an intrinsic feature of many hippocampal neurons is the superimposition of gamma patterns upon the predominantly 5–7 Hz theta rhythm (Buzsaki, 2002). That the hippocampal formation, along with the amygdala, has the lowest threshold for seizure induction is well known (Gloor, 1997).

The second environmental measure, atmospheric power, revealed similar effects. Again the cerebral region most consistently correlated with this inference of energy between the ionosphere and the earth's surface was the right frontal lobe. Atmospheric power, measured in Gigawatts, reveals the consequences of the interactions between energetic particulates within the earth-ionospheric cavity. This is a potentially important ancillary measure for electroencephalographic correlations because magnetohydrodynamic waves generated within this medium can propagate to the earth's surface.

In both Experiments I and II the correlation between power within the gamma range and either geomagnetic activity or atmospheric power was negative. This means that as the geomagnetic activity or atmospheric power increased the cerebral activity within this band decreased. The most parsimonious explanation would be an increase in omega-complexity as defined by Wackermann (1999). An increase in cerebral signals with clusters of faster rise-times, plateaus and drops (as opposed to more sinusoidal 40 Hz patterns) followed by protracted periods of minimal activity would result in greater solutions for complexity while the averaged areas under the curve within this band would decrease. Such patterns are typical of burst-firing neurons. Burst spiking of a single cortical neuron can modify the global patterns of brain activity associated with distinct states of arousal (Li et al, 2009).

Why the right frontal region was preferentially affected remains to be explained. The right hemisphere displays about 10% greater blood flow than the left hemisphere and the white matter/grey matter ratio is also greater by about 10% (Kolb and Whishaw, 1990). The right hemisphere has much less regional organization than the left and behaves more as a homogeneous parallel processing aggregate than a cluster of serial processors (Dimond and Beaumont, 1974). The former property has been employed to explain the right hemisphere's strength as a simultaneous, non-verbal representor of spatial patterns while the left hemisphere is more specialized for the type of serial sequencing associated with the temporal information in language.

The special sensitivity of the right hemisphere in general and the right frontal lobe in particular to increased geomagnetic activity or atmospheric power has significant implication for human behaviour individually and in groups (Davidson and Hugdhal, 1995). First, the integrity of the right prefrontal region strongly contributes to accurate reconstruction of autobiographical memories (Buckner and Petersen, 1996). Disruption is more likely to interfere with the normal ability to discriminate between the veridicality of wishes, dreams, and events that actually occurred. Secondly, the right prefrontal region, because of its importance in contextual information, is intimately involved with appropriate social interactions. They are strongly affected by spatial distances and configurations (Hall, 1966).

Third, the right frontal area has powerful functional, primarily inhibitory, connections with the right parietal and temporal regions. Consequently diminished power or inhibitory frontal functions can encourage disinhibition of functions within the caudal region. The resultant stimulation of activity would produce a sympathetic dominance (arousal), a phenomena that was also shown by Babayev and Allahverdiyeva (2007) during moderate magnetic storms.

Such asymmetric right hemispheric arousal would be more likely to encourage periods of increased vigilance, and in the extreme case panic attacks, as well as the intrusion into left hemispheric awareness of the right hemispheric analogue of the self: the sensed presence (Booth et al, 2005). All of these phenomena have been correlated with increased geomagnetic activity. It is relevant that the experient may not be aware of these effects. The primary cerebral region associated with responsiveness to novel stimuli in the absence of awareness is the right prefrontal area (Berns et al, 1997).

Given the physicochemical and electrophysiological substrate upon which electroencephalographic activity and

human cognition are superimposed, there are likely to be multiple cellular, biomolecular, and membrane mechanisms by which increased geomagnetic activity and atmospheric power directly affect brain function. We suggest that ultimately all of these effects can be reduced to the essential congruence of the magnitude of energy density within the human brain and the geomagnetic field. Like the essential conduits of electrical wiring or telephone exchanges the communication of signals and hence information depends upon an intercalation of similar magnitudes of energy or power (energy/s).

As shown in Fig. 1, the range of atmospheric power during our measurements was 1 to 4×10^{10} W. If one assumes the satellite distances from which these measurements were inferred was about 800 km above the earth's surface the volume would be about 1.5×10^{20} m^3. Assuming the energy was more or less evenly distributed the density would be between 0.7×10^{-10} to 2.6×10^{-10} W/m^3. A similar order of magnitude would be found if the particle flux that reached the altitude of 110 km, a basis for the atmospheric power measure, was employed. The equivalent within a brain with a volume of about 10^{-3} m^3 would be between 0.7 and 2.6×10^{-13} J.

The energy exerted on a charge of 2.1×10^{-19} As from an action potential with an absolute change of 1.2×10^{-1} V (120 mV) would be 2.5×10^{-20} J. This means that the energy of atmospheric power would be equivalent to 10^7 action potentials. Assuming one contributing neuron averages 10 action potentials per sec (10 Hz), this would involve about 1 million neurons per sec. This number is well within the range that could affect this degree of electroencephalographic power over the frontal region.

It may be relevant that in Fig. 3, the global frequency, which is a crude indicator of general activation and energy absorption, increased dramatically above 20 GW. This would be equivalent to a change of 0.4×10^{-12} J–0.6×10^{-12} J within the brain and given the same population of neurons would suggest a 1.5 times increase in base frequency. This corresponds to the Phi value of approximately 38 Hz value compared to the steady values of about 25 Hz below 20 GW. It is also consistent with the averaged slope of 4.7 Hz per 10 GW.

A shift of geomagnetic activity of only 25 nT also has the potential to change the energy available within the brain. The energy stored with a magnetic field can be expressed as B^2/u multiplied by the volume where B is the strength of the field and u is the permeability. Within the volume of the cerebrum (10^{-3} m^3) the energy would be about 2×10^{-13} J. Consequently either the change in atmospheric power or the increase in geomagnetic intensity within this range would provide comparable changes in energy within the brain volume.

Of course this is not a proof that energy absorption within the brain occurs from changes in either geomagnetic activity or atmospheric power. Correlates between EEG power and increases in geomagnetic activity may be due to general changes within the body's chemistry or physiology. For example geomagnetic disturbances with aa (average antipodal) values exceeding 30 nT reduce nocturnal excretion (and presumably synthesis) of melatonin in human beings (Burch et al, 1999). Because melatonin has anticonvulsant properties, its suppression could produce a non-specific enhancement of lability particularly within the temporal lobes that would be manifested during the procedures of EEG measurement.

However, our quantitative estimates do suggest quantitative similarities in energy density within the brain and the changing geomagnetic environment. Subrahmanyam et al (1985) found clear changes in the proportion of alpha rhythms when supine subjects were exposed to experimentally generated magnetic fields designed to simulate geomagnetic pulsations with intensities in the nT range. The orientation of the subject in the geomagnetic field affected the phenomenon. Similarly sleeping in an E–W geomagnetic direction compared to a N–S direction shortens the onset of dream (Rapid Eye Movement, REM) sleep (Ruhenstroth-Bauer et al, 1993). On the basis of the successful experiments with rodents (Michon and Persinger, 1997), we predict that a more precise modelling of experimentally-generated magnetic fields to simulate geomagnetic activity in both pattern and intensity will produce exact changes within the same frequency bands and power levels as natural conditions.

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